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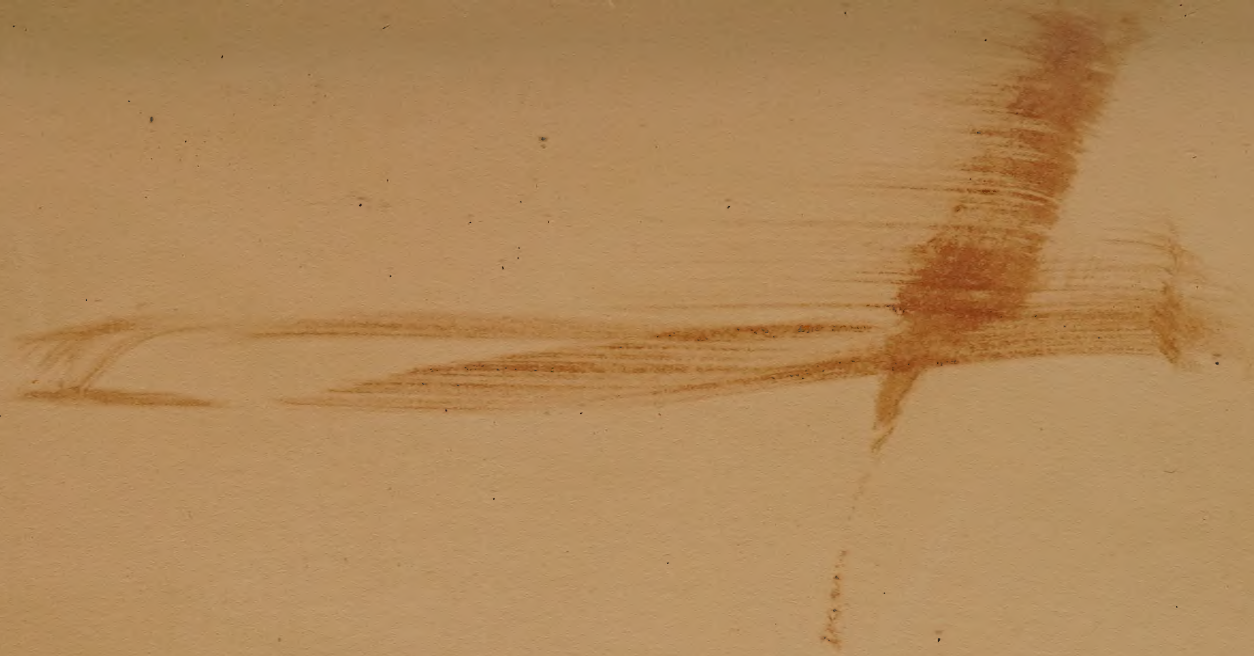

REPORTS OF THE SWEDISH DEEP-SEA EXPEDITION. VOL X
SPECIAL INVESTIGATIONS. NO. 1

THE DISTRIBUTION OF RADIUM IN DEEP-SEA CORES

BY

VIKTOR ST. KRÖLL

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Introduction

In order to explain the deficiency of thorium and radium in sea water compared to the uranium content, Hans Pettersson (1937) advanced the hypothesis of a sedimentation of thorium and ionium together with the carrier ferrihydroxyd. If this assumption is correct the elements of the uranium family in the upper sediment strata should not be in their radioactive equilibrium. Piggot and Urry made use of this hypothesis to date various deep sediment layers with the aid of equivalencies and the laws of radioactive decay (»Per cent of Equilibrium Method»). They obtained values for the rate of sedimentation of the red clay and the globigerina ooze (Piggot and Urry, 1941) in the Atlantic, the Caribbean Sea and the Pacific. The material collected during the Swedish Deep-Sea Expedition made it possible to extend such investigations. Thirteen cores from the central and western Pacific and four cores from the Atlantic were made object

of this study. As the aim was to plot curves of the radium distribution with the greatest possible degree of accuracy, stress was laid upon the upper parts of the cores, which were divided into thin samples. During the course of examination it became evident that the problem of radium in the sediment was more complicated than could be foreseen from PIGGOT's and URRY's investigations (see KRÖLL, 1954). Thus it appeared that the understanding of the geochemical behaviour of the radioactive elements is the essential basis for a successful interpretation of the results.

The first result obtained from these measurements was a framing of the fundamental questions which, together with the answers, are discussed in this paper. The problem of radium will be treated in as general a way as possible, although the proper purpose of investigating radioactive elements in sea water and sediments, besides the geochemical interest in these elements, evidently lies in its adaptability for age-determinations. Preliminary results in this direction are reported, but no definite conclusion can be given so far. Hence the measurements and explanations discussed in this first study need some complementary additions which will be issued in the following numbers of this report.

Acknowledgements

Professor HANS PETTERSSON made it possible for me to carry out this work. For this and for his valuable advice I wish to express my sincere thanks.

Many interesting and stimulating discussions with Dr. F. KOCZY, and his prompt willingness to help, were of great value to me.

May best thanks are due to Dr. B. KULLENBERG and M. R. BERRIT for their positive suggestions.

The author wishes to express his gratitude to the translator Mrs. E. JERLOV.

Finally I also wish to thank the assistants in the laboratory for their able help in the work.

Method and Chemical Preparation of Samples

According to the emanation method the radium measurements were carried out on two apparatus. One of them as per F. KROPF[1]) (1939) had ionization chambers with a diameter of 13 cm and a height of 20 cm. The other, based on the same principle embodied some technical improvements by F. KOCZY, whereby the capacity of the instrument — at an equal chamber volume — was reduced by half, while the sensitivity was doubled. Fig. 1 shows this instrument with ionization chambers consisting of a cylinder from copper plate (to reduce the background), 15 cm in diameter and 13 cm in height. The cables to the electrometer were kept as short as possible and shielded by wide tubing. The closing and opening of contacts was done by relay. Anode batteries of 120 V served for both instruments as chamber voltage. Nitrogen, at least four weeks old, was used as filling gas and silica gel for the drying procedure. The electrometer was a »Einfaden-*Wulf*». The sensitivity for one apparatus amounted to $3.2 \cdot 10^{-13}$, for the other to $1.6 \cdot 10^{-13}$ g Ra/scale unit for 30 minutes charge. Standardization was accomplished by standard solutions of PTR 1901 of $8 \cdot 10^{-11}$ g Ra and NBS 1951 of $5 \cdot 10^{-11}$ g Ra (prepared from a 10^{-9} g Ra solution). The de-emanation of the solutions to be measured was performed by 20 minutes bubbling of a quantity of nitrogen corresponding to the chamber volume.

For the chemical preparation air-dried sediment samples were ground in an agate-mortar and dried for 20 hours in the heating chamber at 105° C before being weighed. In addition, all necessary glass utensils were boiled in diluted $HCl + BaCl_2$ and then carefully rinsed with distilled water before being used. The routine extraction took place by several heating

[1]) The apparatus described by KROPF was constructed several years earlier by PETTERSSON and used by him, RONA and others at the Oceanographic Institute.

procedures with HCl, the last time with the addition of perchloric acid. Then the sample was treated with diluted HCl (1: 3) and filtered. The filtrate, about 100 cc, was put into a suitable storage flask for measuring and the insoluble part saved for control tests. The amounts of sediment treated varied between 0.3 and 2 g. The radium-freedom of used chemicals and vessels, as well as the constancy of the measuring apparatus was checked at intervals and was found to be within the experimental errors. Some samples were measured twice or even several times, at which the fluctuations of the values measured lay within the limits of error.

To make sure that the above mentioned HCl solution really contained the entire radium in the sample, parallel radium determinations were carried out on two homogenized samples of Core 59; one half of the samples was dissolved by means of carbonate fusion; the alcaline fraction obtained by treatment of the smelt with hot H_2O and filtration was measured as well as the acid solution obtained by solution of the precipitate in HCl. The other half of the sample was submitted to the usual HCl extraction and the undissolved residuum was brought into solution by fusion with carbonate and examined. Both samples treated with different chemical methods gave the same value of radium as shown in Table 1. Further, parts of 23 samples, which parts were insoluble in HCl, were fused in nickel crucibles with carbonate mixture. (To avoid contamination by the Pt-crucibles, all carbonate fusions were made in nickel crucibles, Føyn and others 1939). The samples were chosen from layers of maximal as well as minimal radium content. Usually the acid solution only, but in some cases also the alcaline solution of the smelt was measured. For the sample from Core 87, 38—39 cm, the smelt was directly treated with HCl and the solution separated from the siliciferous precipitate by filtration. In all cases the concentration of radium was below 7 % of the radium content in the main solution, often even below measuring accuracy. Table 1 presents the explicit values. For the examined sediments, therefore, it may be concluded that by measuring the HCl-solution obtained by the HCl-extraction method, described above, the total amount of radium was determined without sensible losses.

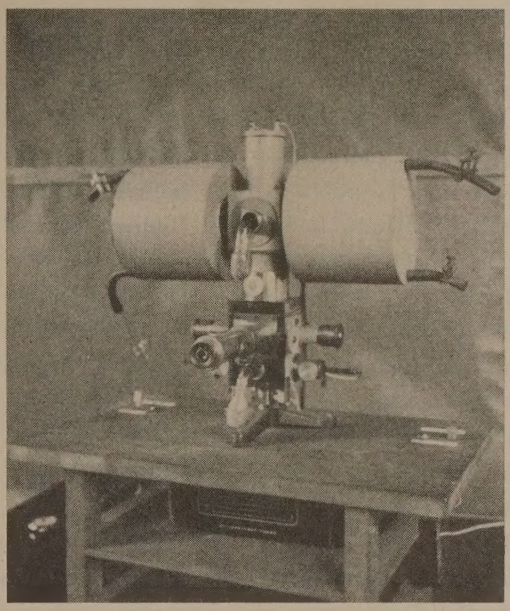

Fig. 1. Apparatus for radium measurements.

Results

In Table 2 the values of radium concentration measured in Cores 69 B, 76 B, 76, 83 B, 83, 85 B, 85, 86 B, 86, 87 B, 87, 98 B, 101, 238, 251, 281 A and 281 are shown. Station number, position, depth and core length are at the head of the respective tables. Except for the last three, the samples of Core 69 B were measured by Professor Hans Pettersson.

The experimental errors depend on the amount weighed, the duration and number of measurements, and also on the absolute amount of radium present (in accordance with the Schweidler fluctuations). In addition, errors are introduced by the chemical treatment, such as

radium losses and contamination. In general the total error will be found to be $\geq 0.3 \cdot 10^{-12}$ g Ra/g sed, or 5—10 % of the determined values. If errors are higher they are given in the table. The detailed description of the calculations is published by KOCZY (1949 a). Table 3 shows the integral radium content (ionium-supported) of a sediment column of 1 cm² cross section for the cores in which the decay of Ra attains equilibrium with uranium. A mean value (Table 3, column 2) of the water content was obtained from determinations which will be published in the »Reports of the Swedish Deep-Sea Expedition». A density of 2.6 for the dry sediment was assumed. The equivalent radium content for a water column of 1 cm² cross section and the mean depth of the ocean was estimated from the mean value $1.3 \cdot 10^{-6}$ g U/l and given for comparison. The radium content of the sea water, amounting to about 20 per cent of the uranium equivalent, was not deducted. The conversion factor Ra_U : U is assumed to be $3.49 \cdot 10^{-7}$.

Figures 3, 5, 7—10, 12—17, 19 and 20 illustrate the radium values in some cores as well as the values of MnO_2, Fe_2O_3 and $CaCO_3$, kindly placed at my disposal by H. ROTSCHI and R. BERRIT (cf. legends). The echograms of the ocean floor for the corresponding stations are shown in Figs. 6, 11 and 18. A complete statement of these as well as of the chemical measurements will be published elsewhere in the Reports of the Swedish Deep-Sea Expedition.

General Views on Radium Distribution in Sediments

In investigating the problem of radium in deep-sea sediments, either from the geochemical or geochronological point of view, a number of questions arise, which call for an explanation.

A) Concerning the distribution of radium in the sediment in situ represented by the core:
   1. Has the scale of length been changed by the sampling or
   2. has the distribution of radium in the core been changed during the transport or storage of the core?

B) As to the genetic history of the radium:
   1. Is the radium in the sediment supported by uranium, where uranium is present, either
      a) in minerals (terrestrial or submarine) or
      b) in chemical or biological precipitates from solution in the ocean water?
   2. Is the radium ionium-supported
      a) by minerals from which uranium was eluted or
      b) by precipitation or adsorption of the ionium present in ocean water or
   3. is the radium present without its ancestral elements, *i. e.* »unsupported», after it has become precipitated or adsorbed?

C) Accordingly, the factors which influence the distribution of radium in the sediment:
   1. Has the supply of radium, ionium and uranium been constant during the unit of time or was there
   2. a variation in the rate of sedimentation
      a) due to dilution by inactive sediment or
      b) due to dissolution of parts of the sediment such as carbonate or silica or
      c) a horizontal transportation of sediment, e. g. by erosion or deposition or
   3. was radium, ionium or uranium displaced by diffusion and afterwards immobilized through adsorption or was there
   4. a transportation of Ra by burrowing animals or by the activity of bacteria or
   5. by submarine slumping?

ad A) 1. *Influence of the »Sampling» on Radium Distribution in the Cores*

Three different core samplers working on two different principles were used. The »long cores» marked with simple numbers, were collected with the KULLENBERG piston core sampler. Owing to its effective »pressure and sucking» principle, the sediment throughout these cores is likely to be undisturbed in its distribution. One must assume, however, that from the upper end, (in particular through spilling of sediment along the walls of the sampler) more than 10 cm may sometimes be lacking. (KULLENBERG, 1947). These cores were preserved water-tight, so that contraction of length due to loss of water was less than 1.5 per cent during transport and storage and it can, therefore, be neglected.

The A- and B- Cores were collected by means of an EKMAN core sampler with 4 and 3.5 cm diameter respectively. When using this sampler, it is probable that less than 1 cm of the uppermost part of the sediment was lost. But the original radium distribution in the sediment may have altered as follows (KULLENBERG, l. c.): as soon as the core sampler penetrates into the bottom, the sediment which has entered the coring tube acts as a piston braked by friction against the wall. On account of the friction this »sediment-piston» brings pressure to bear upon the sediment below. This pressure is dependent on the diameter of the sample tube, on the character of the sediment and tube, as well as on the penetration velocity of the tube and on the length of the sediment piston, i. e. the core. The sediment below the mouthpiece of the tube will partly, according to its property, be pressed aside and so a part of the sediment is lost. Naturally no selection of radioactive material takes place during this process and so the radium concentration in the sediment is not changed. Thus sampling cannot cause maxima and minima. One cannot readily make an estimate of the distortion occurring. No attention is paid to PIGGOT's attempt on varved clay (PIGGOT, 1941; URRY, 1948) as this would be a too far-reaching extrapolation. Some experiments on spilling and distortion will be started soon in this institute. Owing to the simple methods of preservation, the water loss in the short cores was considerable. The contraction found by comparison with the cut-record on board was aportioned over the total core length and considered in the »Depth Records» of the samples.

ad A) 2. *Change in Radium Distribution in the Cores during Transport and Storage*

In this connection the diffusion of radium and uranium has to be considered. In the first place the atoms or ions which are not inherent in minerals are subject to a concentration movement on account of diffusion in interstitial water and on the surface of sediment particles. The time for the diffusion process during storage is negligible compared with the age of the radium in the sediment, so that the temperature and pressure fluctuations to which the sediment is exposed during lifting from the ocean floor, can never neutralize the time factor as long as the character of process entailing the diffusion is the same. The question becomes, however, more significant if one reckons with the water movements and the oxidation process in the sediment after sampling. The sediment generally contained 50—80 per cent H_2O which was reduced to 8—12 per cent before samples were taken from the B-core. This implies a convection of water possibly compensating the time factor, so that the diffusion during the few years of storage may be comparable with the diffusion in the ocean floor. For uranium in particular it is essential that the core is oxidized in the air, by which 4-valent uranium can be converted into soluble 6-valent uranium in which state it will also diffuse more easily. Experiments by the present writer have not yet been carried out on this subject, but some conclusions may

be drawn from another experiment. According to the ATTERBERG procedure a sample was decanted in three size-fractions $< 3\,\mu$, $3-30\,\mu$ and $> 30\,\mu$ and the radium content measured. If the radium were loosely adsorbed on the sediment, or present in the electrolyte content, it would be easy to wash it off with the three liters $H_2O + H_2O_2$ used for the decantation, and after evaporating the water, measure it together with the smallest fraction. The three fractions gave values of resp. 2.4, 8.3 and $3.9 \cdot 10^{-12}$ g Ra/g; thus the second fraction shows a clear maximum. This means that in sediment rich in calcium carbonate, with about per cent 3 Mn (our particular sediment) the radium is so stable that diffusion during storage is not likely to have occurred.

ad B) 1.a) and b) *The Significance of Uranium for the Radium Distribution*

Table 4 of the uranium measurements, published with the consent of F. HECHT, shows on the whole that uranium and radium in deeper sediment layers are in equilibrium. The radium curves also show that the radium in all cores of sufficient length is reduced to a fairly constant value of about $0.5-2.0 \cdot 10^{-12}$ g Ra/g which is maintained towards greater depths. In the Pacific the uranium equivalent is about $0.5-1.0 \cdot 10^{-12}$ g Ra/g which corresponds to the uranium content of the ordinary basic rocks, the disintegration products from which constitute the main part of the sediment in these regions. HECHT found also higher uranium values, e. g. in Core 76 at depths of 40 and 200 cm and in Core 87 B at 46 cm. A few uranium mineral grains (DUPLAIX and CAILLEUX, 1952 found sporadically in some cores zircon and titanit) whether of submarine or terrestrial origin, would suffice to explain the measured anomalous uranium values. Another alternative would be, that the uranium had been precipitated or adsorbed from the sea water. If so — under certain conditions — the layers could be dated with the aid of the U/Io — relation. Judging from the experience so far gained, the »uranium-supported» radium is of no great importance as it is hardly present in the upper parts of the cores, for which the rate of deposition can be estimated. An age determination from uranium can only be arrived at in the above mentioned hypothetical case.

ad B2 a and b). *Ionium-supported Radium*

Uranium usually being more soluble than ionium, it is probable that mineral fragments are deposited from which the uranium has been extracted. The way in which ionium is bound in the sediment does not affect the age-determination. Ionium precipitation or adsorption from the sea water is probably much more important. As mentioned in the introduction, the deficiency of thorium and radium in sea water has led to the theory of ionium precipitation (PETTERSSON, l. c.). The fact that the radium in the sediment is ionium-supported is confirmed by the curve trend found for radium, uranium determinations by URRY (1941), HECHT and KRÖLL, as well as direct ionium determinations made in Brussels by E. PICCIOTTO, (PICCIOTTO and ISAAC, 1953). Usually it is assumed that ionium is due to aftergrowth of uranium dissolved in the sea. But as F. KOCZY has shown the ionium surplus in the sediment (discussed in greater detail below) can also be explained by the supply of ionium with river water. Accordingly uranium was deposited in a reducing environment, whereas ionium was distributed fairly uniformly on the floor (KOCZY, 1953). Anyhow, it may be gathered that mostly unsupported ionium, from which the radium is produced, is received on the bottom. This provides the basis for a possible age determination from radium measurements as carried out for the first time by PIGGOT and URRY (l. c.).

ad B3). *The Role of Unsupported Radium*

After 10 000 years the unsupported radium in the sediment is reduced to one per cent; it is therefore of little importance for the chronology of the deep-sea sediment as long as the geochemistry of Io and Io-supported Ra is not quite clear. As the curves show (the radium concentration increases just below the sediment surface), the percentage of unsupported radium in the total content is negligible.

ad C1) *The Radium- Ionium- and Uranium Accumulation per Time-unit and their Time- and Space Constancy*

Variations in the radium supply to the sediment may be neglected with regard to B3) as well as variations in the uranium supply according to the measurements. The changes in the supply of ionium bound in minerals are also left out of account according to B2).

The following effects speak in favour of the time variation of the supply/time unit to the sediment from ionium dissolved in sea water: according to the measurement by F. Hernegger and B. Karlik (1935) and G. Koczy (1950) a mean value for uranium content in sea water amounts to $1.3 \cdot 10^{-6}$ g U/l. This value must be considered as constant on account of the slight spreading of uranium contents in the samples for the whole ocean, though, adopting F. Koczy's (1953) value for river water, $1 \cdot 10^{-9}$ g U/l, we must reckon with a doubling of the uranium content in the sea after 60 000 years. The highest uranium contents in the bottom were measured in shelf sediments and Koczy assumes that U^{VI} is reduced into U^{IV} an effect of biogenous material and subjected to sedimentation in different localities (Sapropel). Thus, if the uranium content in sea water is influenced by living organisms one must assume that the uranium content at a constant uranium supply must have fluctuated according to the vital conditions of these organisms. Furthermore, the uranium supply (possibly also the ionium supply according to F. Koczy (cf. B2)) has probably varied with glacial period fluctuations. Also volcanism may have been another variable uranium source. There are accordingly several sources and sinks for the uranium, which may affect and have affected the uranium content in the sea and naturally also the ionium supply to the sediment, as we may presume a mixing of the ocean waters with a period of 100—1000 years.

Although the real reason for ionium sedimentation is not known, there is reason to believe in a time- and space- change of the ionium supply. If the ionium is deposited together with a carrier (e. g. $Fe(OH)_3$), it is adsorbed on the precipitate and is dependent on the concentration of the active anions. — Kulp and Carr (1950) assume (physical) adsorption which should be proportional to the surface of the sediment. A chemisorption would be dependent on the character of the depositing material or the sediments and on the chemical conditions (pH etc.). If the ionium is extracted from the sea by biological action one must probably accept a variation of ionium sedimentation with the biogenic components of the sea water. On the whole it would be very surprising if the ionium supply did not change with time and space, which would entail maxima and minima in the radium distribution. Assuming that the rate of deposition, but not the ionium supply to the sediment, was constant in time, one would find out, from the trend of the radium curve, the actual conditions in the sea, as, for instance, variations in the uranium content or climatic-biological alterations which affect the deposition of ionium. If so, one must proceed as mentioned on p. 12 and accept a time-cm-relation at L_0, the first layer of the Io-U equilibrium and standardize the experimental curve of the Ra-decay with the theoretical one according to area and ordinate in L_0.

Thus the theoretical curve demonstrates for the actual interval the radium-decay curve at constant ionium supply. The point of intersection between the ionium-decay curve and the cm-t = 0 axis gives the initial ionium concentration. From this and from the water content and rate of sedimentation, the average ionium supply can be found. The percentage deviation of radium concentration between the experimental and the theoretical curve gives the percentage deviation of ionium supply from the average.

ad C2 a b c) *Variation in the Rate of Sedimentation*

A change in the rate of sedimentation is, no doubt, reflected in the radium distribution in the sediment. A modification in the sediment composition with time or space, such as variation in grain-size, biogenous precipitations from calcium carbonate or silica etc., implies an additional sedimentation of inactive sediment causing a change in the radium concentration.

A dissolution of settling biogenous calcium carbonate or silica, with a reduction of the rate of sedimentation and increase in radium concentration as a consequence, is connected with this problem.

Furthermore, we must pay attention to the horizontal transport of sediment. While examining radiolaria in Albatross-cores from the Pacific, RIEDEL (1952) found evidence of erosion as well as of deposition of eroded sediment. He found in several cores from great depths to the surface of the sediment, Tertiary radiolaria, partly mixed with more recent ones, partly unmixed. From the abrasion of the radiolaria he concludes that there are places where the sediment is carried off as well as places where it accumulates, thus horizontal transport occurs. The presence of radiolaria of the Oligo- and Eocene at the sediment surface indicates an erosion of 10 m sediment at several localities, for a probable rate of deposition of 1 mm/1000 years. It is chiefly old inactive sediment (the 40 cm of active sediment of recent origin is negligible compared with a layer of 10 m), which is eroded and deposited and is traced through a change in the ionium-supported radium concentration in the upper sediment strata. The horizontal transport of sediment is due to bottom currents, possible tectonic change as well as submarine volcanism (see below).

Provided that alterations of the vertical radium distribution in the sediment are due exclusively to variations in the rate of sedimentation, these variations are found in the following way: the average rate of sedimentation is derived — as in greater detail described below — through a cm-t-relation in L_0. By integrating progressivly from the sediment surface to L_0 and comparing the integral curve of the theoretical radium-decay curve for the sediment, we obtain a chronology of the different sediment layers from which the variation in rate of deposition is readily ascertained (cf. Fig. 2). For this determination we must reckon not only with constancy of ionium supply, immobility of radium and no submarine slides, but also constancy of water content in the sediment considered, as these measurements are expressed in grams of dry sediment and the water content is included in the conversion from mm/1000 years to g/cm² year (KOCZY 1951). The calculation of changes due to intensity of sedimentation has been avoided, as a depth scale of g/cm² is not easily introduced for practical work on sediment.

ad C3) *Diffusion and (Re-) Adsorption of Radium*

Considering that the precipitation or adsorption of an ionium-atom or ion is effected by the chemical behaviour of Io, there is reason to believe that the ionium in sediment is mostly immobile. On the other hand, a radium atom or ion produced by radioactive decay is probably chemically unaffected at the place

of its birth and it will, therefore, more easily diffuse. It is an open question as to how far it must diffuse to get fixed at some place and what would be the characteristics of such a place. The ionium determinations which are being carried out by PICCIOTTO in Brussels, however, may cast some light upon this problem. Experiments regarding the diffusion velocity of radium in the sediment are being conducted here in this Institute as well as experiments concerning a more detailed classification of the sediments rich in radium.

ad C4) *Reshuffling of Sediment by Worms and Bacteria*

Living organisms in the sediment may influence the radium distribution. A cursory study of the sediment shows a levelling of the radium distribution curves with depth. Maxima and minima could, however, appear through changes in the chemical environment of the sediment due to the activity of living organisms, so that the diffusion- and adsorption power is chiefly affected. But the radium being generally the least soluble of the alkaline earths metals, may remain almost immobile, and it is apt to replace the other alkaline earths metals e. g. Ba in their fixed position.

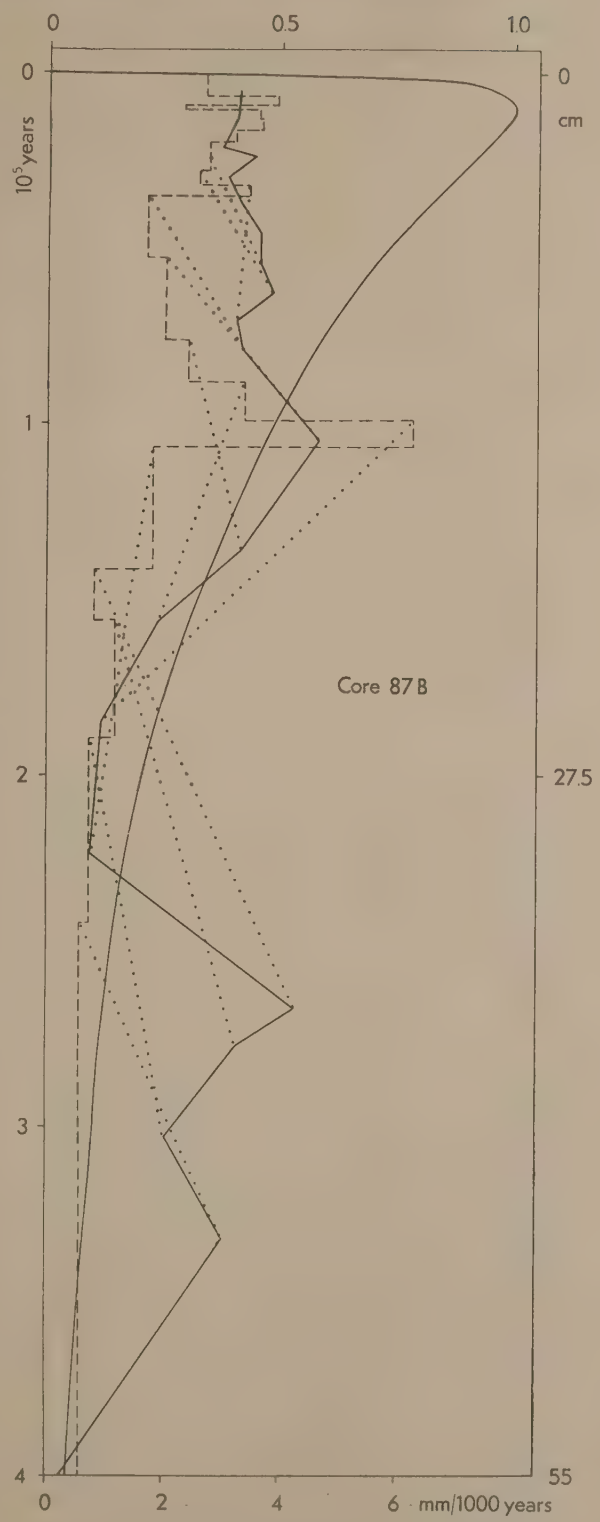

Fig. 2.

Fig. 2. The determination of the rate of sedimentation in Core 87 B. Thin fulldrawn line: the theoretical distribution of the radium concentration in the sediment with time, assuming a constant rate of accumulation of unsupported ionium only. Thick fulldrawn line: measured radium distribution less the uranium equilibrium $0.5 \cdot 10^{-12}$ g Ra/g, which is normalized according to surface on the theoretical curve with the association 55 cm = 4.10^5 years. The radium content of the manganese nodule (35.6—36.7 cm) was not taken into account. Dashed line: the rate of sedimentation in mm/1 000 y with time. This curve was derived in the following way: according to the association 55 cm = 4.10^5 y a mean rate of sedimentation of 1.4 mm/1000 y is represented by the theoretical radium curve. Integrating the measured curve, the radium content is got as a function of depth (cm). Integrating the theoretical curve, the radium content is got as a function of time (t). Comparing these two functions a dating of the different levels (t-cm-relation) is established from which the rate of sedimentation in the considered intervall may be found. Dotted lines give the relation t-cm.

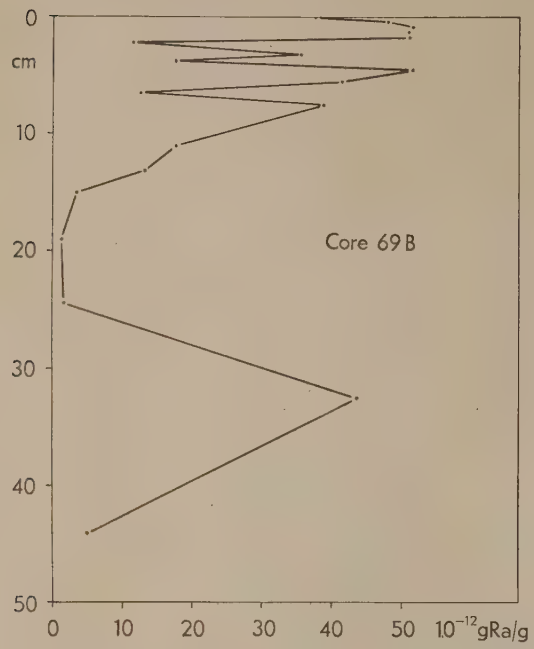

Fig. 3. The distribution of radium in Core 69 B.

ad C5) *Submarine Slumping*

The occurrence of submarine slumping does not permit us to speak about a rate of sedimentation. It is visible mainly on the echograms, when submarine slumping must be taken into account.

One may gather from item C), for the various influences on the vertical distribution of radium in the sediment, that attempts have been made to describe the methods which lead to a determination of the rate of sedimentation. In practice an all-round examination of the cores must be made in order to arrive at a suitable combination of the methods for determining the rate of deposition. The results reported in this paper are not sufficient, as ionium and uranium observations, as well as mineralogical investigations, are lacking.

Another method may be adduced which admits the determination of the average rate of sedimentation over a long period of time and with the least possible assumption as to the above influences (KRÖLL 1953). The sediment depth in which the equilibrium between uranium, ionium and radium is attained within the errors of measurements and below which no radium above the equilibrium value with uranium is present, is represented by L_0. A cm-t-relation is attempted, e. g. $L_0 =$ 330 000 years ($\backsim$ 4 half periods of ionium). As a check on this arbitrary relation, one standardizes the area of a theoretical radium-decay curve assumed for ionium sedimentation with the experimental one and tests the conformity of experimental and theoretical radium concentrations for 330 000 years. This conformity within the limits of error must be achieved by the adaption of the cm-t-relation in L_0. It must be observed that the rate of deposition at the depth L_0 does not deviate much from the average rate of sedimentation, which, in this way is obtained for the corresponding time. Another assumption is that the radium concentration in L_0 has not been much changed either by diffusion or by deviations in the ionium supply from the mean value.

The Cores from the Pacific

Core 69 B. Station 102. Position 13° 25′ S 149° 30′ W. Depth 4615 m. Core length 45.4 cm.

General description: the core consisted of red clay with numerous philipsite crystals. The content of calcium carbonate in the upper layers of Core 69, taken at the same station, fluctuates between 3 and 14 per cent.

Distribution of radium concentration: four narrow, sharp maxima with a concentration of $40-50 \cdot 10^{-12}$ g Ra/g, which are separated by three minima of $10-20 \cdot 10^{-12}$ g Ra/g, with a minimum at a depth of 15 cm. Then the radium concentration increases below 25 cm to a new maximum of $44 \cdot 10^{-12}$ g Ra/g and towards the end of the core at 44 cm, it is reduced to $5 \cdot 10^{-12}$ g Ra/g. At 50—55 cm the Ra-concentration should have attained the

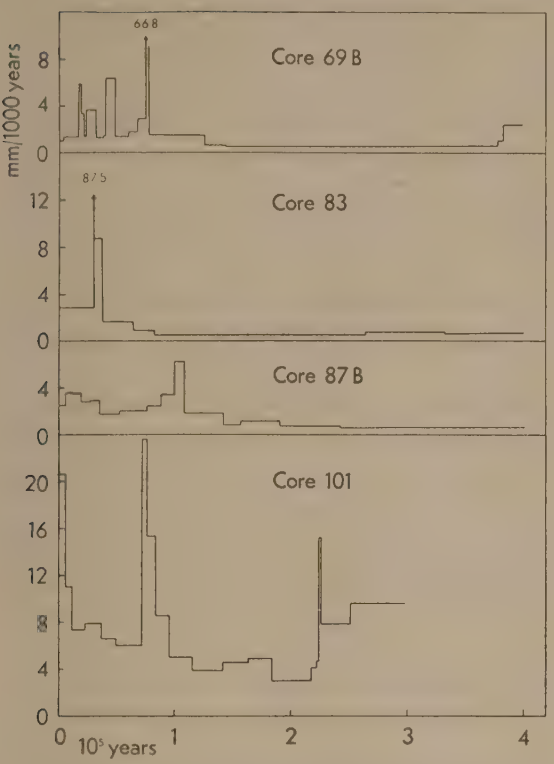

Fig. 4. The variation of the rate of sedimentation with time in cores 69 B, 83, 87 B, and 101. At the arrows, the rate of sedimentation is according to the indicated value.

U-equilibrium. Unfortunately this core is too short to illustrate this, but a comparison with curves for other cores supports this view. The average rate of deposition amounts to 1.3 mm/1000 years. The uranium equivalent is $1.5 \cdot 10^{-12}$ g Ra/g according to HECHT, 0.5—$1 \cdot 10^{-12}$ g Ra/g according to radium measurements in the minimum between 15—25 cm.

The question arises as to how these maxima and minima should be explained. By appearance the sediment is homogeneous and at the surface probably less than 1 cm is lacking. — Apparently the trend of the curve is *not* induced by time fluctuations of the uranium content in the sea water, although, according to Table 3, the integral radium content in the sediment is 3.1 times as great as the uranium equivalent value of the water, thus suggesting a time alteration of the uranium content. But as *all* cores have not the same radium distribution, local conditions seem to predominate.

The variation of the ionium supply due to changes in the character of the sediment (adsorption power etc.), or of the chemical sedimentation conditions, would be a satisfactory explanation. In that case we must reckon with deviations from the mean supply of an order of 1:8, and with a fairly large one between 100 000 and 200 000 years.

The interpretation of the curve, considering variations in the rate of sedimentation, is clear from results given in Fig. 4, with alterations in the rate of deposition by the factor 100. The calcium carbonate content is low and almost constant. The alteration of the silicate part as observed in Core 83 does not yield adequate information. The effects mentioned are likely to have been produced by horizontal transportation of deposited sediments as a consequence of volcanic activity.

It is unlikely that the curve is to be explained by diffusion and adsorption only. In that case one would have to distinguish between mobile and immobile radium and also to assume that the relation between immobile and mobile radium varies with the adsorption power of the sediment. This would entail a concentration decrease of mobile radium from the Ra-minimum at 15—25 cm to the two adjacent maxima. This decrease should cause a radium diffusion sufficiently high to maintain the high radium concentration which exceeds the ionium equivalent at the maxima. Thus, one arrives at extreme assumptions leading to incongruity if one tries to argue that the t-cm-correlation in L_0, due to diffusion, is essentially false. But a small part of the radium may be supported by diffusion. — Therefore we maintain the approximate accuracy of the average rate of deposition.

An interpretation of the curve according to C4) by action of worms and bacteria is, as mentioned, not probable. — Submarine slump-

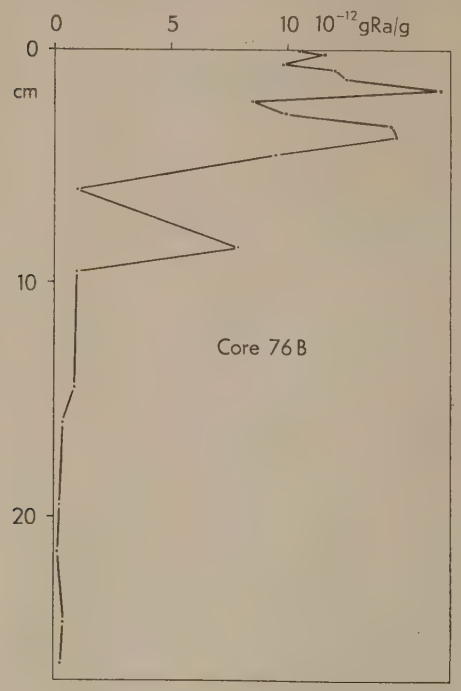

Fig. 5. The distribution of radium in Core 76 B.

ing is not involved, as four cores in a large area of the central Pacific show a consistent radium distribution.

Core 76 B. Station 114. Position 3° 45′ N 149° 44′ W. Depth 5155 m. Core length 29.5 cm.

General description: 12 cm, red clay poor in calcium carbonate with numerous radiolaria, below 12 cm fine calcareous ooze.

Distribution of radium concentration: uppermost we encounter again three narrow sharp maxima; at 10 cm the radium concentration is reduced below $1 \cdot 10^{-12}$ g Ra/g and retains this value to the end of the core. This low value may be due to the higher rate of calcareous sedimentation. The method of determining the average rate of deposition fails for this core. Nevertheless, there remains another possibility to arrive at a value, though very approximatively (Pettersson 1951). If a certain amount of ionium per year and per liter sea water is deposited, we get an initial value of the ionium concentration in the sediment surface, which depends on the rate of sedimentation. If it is not too far from the sediment surface the radium concentration in the high maximum of the core is close to the equivalent value for this initial concentration of ionium. From this and from comparisons between the maxima of different cores, we may estimate the rate of deposition. It should be observed that such a computation with the here adopted value for the uranium content per liter sea water of $1.3 \cdot 10^{-6}$ g U/l gives satisfactory consistency.

For the upper part of Core 76 B a possible rate of deposition of 3—4 mm/1000 years is shown; for the lower part of the calcerous sediment a rate about five times as high is probable.

Core 76. Station 114. Position and depth as in Core 76 B. Core length 1354.5 cm.

General description: 0—17 cm calcareous red clay, 17—59 cm fine calcareous sediment, 59—749 cm poor to somewhat calcareous clay, 749—1354.5 cm calcareous to calciferous clay. Chemical examinations have been made but are, in this core, of little interest for the radium distribution.

Distribution of radium concentration: apart from the calcium carbonate content it shows a regular falling off from the surface to 50 cm or the level of uranium equilibrium. From the stratification of the sediment as well as from the maximum values in Core 76 B it is inferred that no essential part of the surface layer has been lost. On the other hand in Core 76 the high radium concentration in the red clay continues into the calcareous sediment below 17 cm, whereas in Core 76 B this is not the case. Thus the conclusion about the loss of sediment by sampling drawn from the radium distribution in the cores is perhaps not quite correct. The content of calcium carbonate fluctuates very much in the upper

part of the core and it is not, therefore, worth while to convert the radium values to a sediment free from calcium carbonate, as the calcium determinations were made at other levels.

Core 83 B. Station 130. Position 8° 40′ N 169° 28′ W. Depth 5440 m. Core length 30 cm. Topography: according to the echogram (Fig. 6) there is a rather constant slope of the ocean floor by 30 m in 1.2 km.

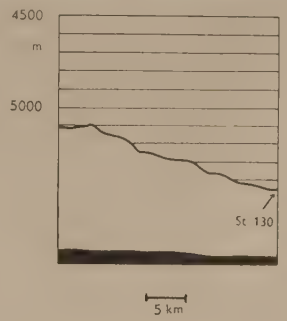

Fig. 6. Bottom topography in the vicinity of station 130.

General description: homogeneous red clay which, through loss of water during transport and storage was shortened from 30 to 27 cm. The curve for ferric oxide and manganese oxide content is also presented in Fig. 7, but does not admit of any special conclusions in view of the radium distribution. The content of calcium carbonate is insignificant.

Distribution of radium concentration: the core is too short to show the second maximum and the transition of the radium decay curve in the uranium equivalent as it appears in Core 83. The highest value of the radium concentration, which is attained at about 9 cm sediment depth, suggests a rate of deposition of 1—2 mm/1000 years according to the described method (Core 76 B).

Core 83. Station, position, depth and topography as in Core 83 B. Core length 295.5 cm.

General description: red clay poor in calcium carbonate with single phillipsite crystals and numerous radiolaria. The content of calcium carbonate is less than one per cent. The curves for the content from MnO_2 and NiO in Fig. 8 is contrary to the trend of the radium curve.

A purely qualitative microscopic study of the sediment showed that the minimum of the radium concentration is associated exclusively with a minerogenous component, the second maximum by a maximum of radiolaria.

Distribution of radium concentration: the radium concentration decreases from $27 \cdot 10^{-12}$ g Ra/g at 4 cm to the uranium equilibrium between 8 and 17 cm. Then it increases to a second maximum of about $45 \cdot 10^{-12}$ g Ra/g and attains definitely the uranium equilibrium at about 46 cm. A comparison with Core 83 B indicates the loss of the uppermost 10—20 cm at sampling. This may imply that the first maximum has a higher Ra-content and hence the factor Ra_{sed}: Ra_{Um} according to Table 3 is increased to 1.5—2.5. The average rate of deposition amounts to 1.2—1.5 mm/1000 years, the loss of the uppermost 15—20 cm being allowed for in the higher value.

As to the alternatives discussed in items C 1, 3, 4, 5, the interpretation of the curve trend is analogous to that of Core 69 B. Some new views on the alterations of the rate of deposition, Fig. 4, are presented below. Con-

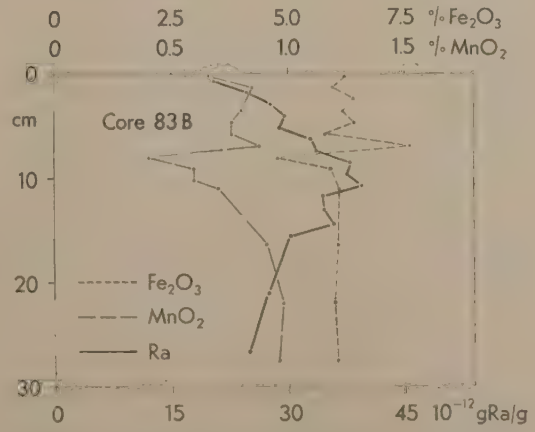

Fig. 7. The distribution of Ra, Fe_2O_3, and MnO_2 in Core 83 B.

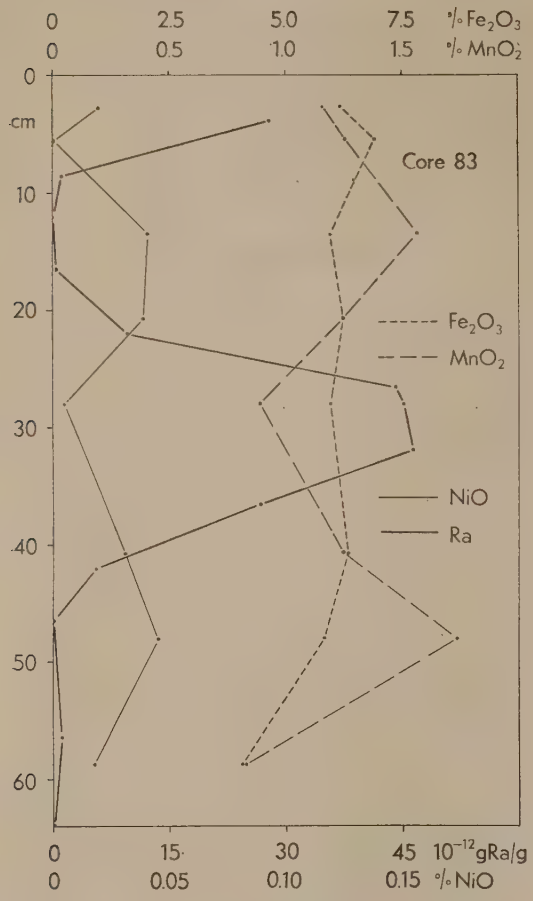

Fig. 8. The distribution of Ra, Fe_2O_3, and MnO_2 in Core 83.

sidering the loss of the upper layers, the high maximum which is now present at about 30 000 years would be shifted towards 100 000 years. This maximum, which is characterized by an almost total absence of radiolaria in the sediment, can only be explained by horizontal transportation, viz. if it is due to a change in the rate of sedimentation. One is justified in assuming that a considerable change of deposition in the central Pacific can be brought about only through a change in the biogenous component which, to begin with, is to be considered as inactive. Then the maximum in the rate of sedimentation should be parallel with a maximum in the content of foraminifera or radiolaria etc. The contrary being the case proves that the variation in the rate of deposition is the cause of the radium distribution, provided that horizontal transportion of sediment occurs. We may imagine this procedure in the following way: the area under consideration in the Pacific is rich in volcanoes. During an eruption of a submarine volcano the basalt bottom below the sediment cover is melted at a certain point and the liquid lava penetrates upwards. The water content of the sediment probably increases upwards and so the property of the sediments become more similar to that of the water. Thus on one hand there is a high heat capacity with cooling of the lava as a consequence, on the other, the sediment is pressed upwards and sideways by the lava. Chiefly on account of the assumed geothermal heat current at this place, the sediment, mostly inactive, is radically carried off. The deposition, naturally, depends on the topography of the bottom and a simultaneous sorting of the sediment according to size, density etc, will take place, which is consistent with the findings of exclusively minerogenous sediment near the minimum of the radium concentration. The eruption of a submarine volcano thus described may result in an intense transport of sediment during a relatively short time. But the lifting of the sediment cover also may entail a transport in a smaller scale by bottom currents for a considerable time afterwards. This may be the cause, according to RIEDEL's investigations, of recent radiolaria being mixed with Tertiary radiolaria at the surface of some cores.

From the radium distribution in this core the following may also be gathered: as the second maximum of the radium concentration appears to be parallel with a maximum of the radiolaria, there possibly exists a connection between them. That means that the content of radiolaria is causally connected with or only an indicator for the amount of ionium supply. This agrees with the known fact that the radium concentration attains

its highest values in radiolarian ooze. The variations in the content of radiolaria are likely to result in MnO_2 and NiO being contrary to the radium content, if Mn and Ni are present in minerogenous form.

Core 85 B. Station 132. Position 5° 34′ N 172° 12′ W. Depth 5590 m. Core length 57 cm.

General description: homogeneous red clay shortened by loss of water during transport and storage from 57 to 50 cm. Content of calcium carbonate probably below one per cent. Content of Fe_2O_3 and MnO_2 in Fig. 9.

Distribution of radium concentration: in this core too, we have two maxima. The first ca. $36 \cdot 10^{-12}$ g Ra/g at 5 cm decreases to a minimum of $3 \cdot 10^{-12}$ at 45 cm, followed by a second maximum of $23 \cdot 10^{-12}$ g Ra/g. The approach to the uranium equilibrium is not included in this core. The mean rate of sedimentation may be estimated at about 1.7 mm/1000 years, considering the decay below the second maximum of radium. The explanation of the trend of the curve is analogous to that for Core 69 B.

Core 85. Station, position and depth as in Core 85 B. Core length 1083 cm.

General description of the examined part: red clay with a calcium carbonate content of less than one per cent.

Distribution of radium concentration: in the upper metre the radium concentration is everywhere below $1 \cdot 10^{-12}$ g Ra/g. Either there is a place of removal, i. e. the erosion exceeds the sedimentation (perhaps because of volcanic action, cf. page 16) or the uppermost 50 cm was lost at sampling. According to a personal communication from M. Riedel to Professor Pettersson there are in the uppermost metre mostly radiolaria from the Miocene and Oligocene, viz. old sediment.

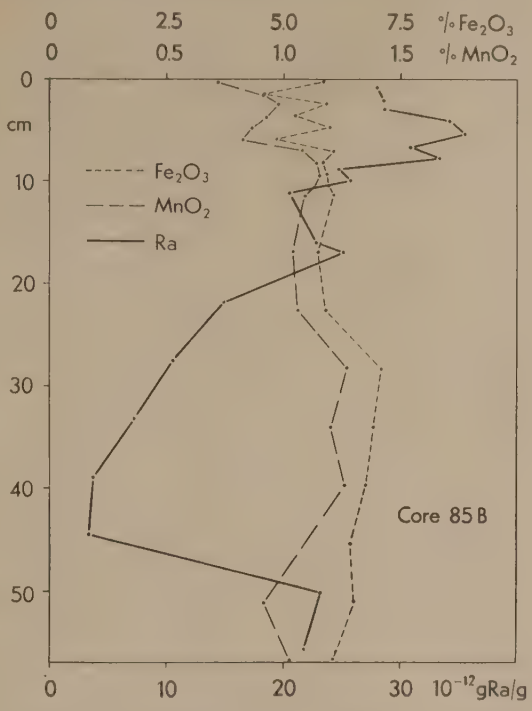

Fig. 9. The distribution of Ra, Fe_2O_3, and MnO_2 in Core 85 B.

Core 86 B. Station 134. Position 4° 02′ N 172° 19′ W. Depth 5500 m. Core length 54 cm.

General description: red clay poor in calcium carbonate, with radiolaria; during transport and storage shortened from 54 to 49 cm. Fe_2O_3 and MnO_2- content appears from Fig. 10. According to measurements in Core 86 the content of calcium carbonate is estimated to be less than one per cent.

Distribution of radium concentration: two adjacent maxima of $50 \cdot 10^{-12}$ g Ra/g are separated by a minimum at 13 cm. The radium concentration below decreases slowly with the depth but does not attain the uranium equilibrium at the end of the core. The average rate of deposition is 1.2 mm/1000 years.

Core 86. Station, position and depth as in Core 86 B. Core length 1038.5 cm.

General description of the examined part: red clay poor in calcium carbonate with

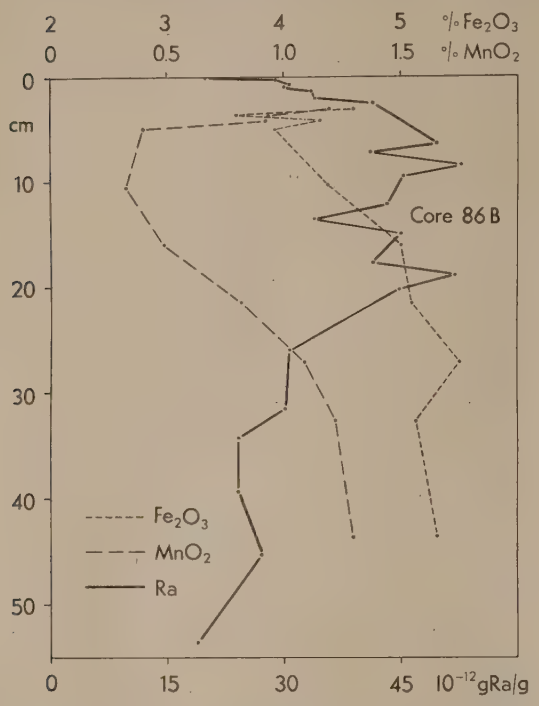

Fig. 10. The distribution of Ra, Fe_2O_3, and MnO_2 in Core 86 B.

numerous radiolaria. Content of calcium carbonate less than one per cent.

Distribution of radium concentration: the distribution of radium concentration decreases from $6 \cdot 10^{-12}$ g Ra/g to $1 \cdot 10^{-12}$ g Ra/g which corresponds approximately to the uranium equivalent. Here is, probably, another place of erosion or of large supplies of inactive sediment in recent time, and thus the radium concentration is very much reduced. Another alternative would be a loss of the uppermost 40—50 cm at sampling.

Core 87 B. Station 136. Position 2° 23′ N 173° 50′ W. Depth 5560. Core length 55 cm. Topography: according to the echogram (Fig. 11) the ocean bottom in the vicinity is rather irregular.

General description: red clay poor in calcium carbonate; shortened by loss of water during transport and storage from 55 to 49.4 cm. The calcium carbonate content may be estimated at less than one per cent from determinations in Core 87. Fe_2O_3 and MnO_2 — content, which are parallel with the radium, is included in Fig. 12. A Mn-nodule of ∽ 8×5×3 mm was found at a depth of 36 cm.

Distribution of radium concentration: two maxima of $33 \cdot 10^{-12}$ g Ra/g and $30 \cdot 10^{-12}$ g Ra/g respectively are separated through a minimum of $6 \cdot 10^{-12}$ g Ra/g between 20 and 30 cm. At 55 cm the radium concentration is reduced to ∽ $2.5 \cdot 10^{-12}$ g Ra/g which is assumed to be near the uranium equilibrium. In the second maximum a Mn-nodule is present with almost $100 \cdot 10^{-12}$ g Ra/g, thus showing 3—4 times more radium than in the adjacent sediment. The weight of the nodule was 0.24 g, i. e. it contained a radium amount of $23 \cdot 10^{-12}$ g. The factor $Ra_{sed.}$: Ra_M according to Table 3, is here 1.8. The average rate of deposition was found to be 1.2—1.3 mm/1000 years.

The interpretation of the radium distribution must be looked upon from a new point of view on account of the presence of the manganese nodule. The radium in the core obviously seems parallel with the manganese content. However, MnO_2 has a pronounced adsorption power for radium (Koczy, 1949 b). Furthermore, according to measurements by H. Pettersson (1942) one must assume that the radium in the manganese nodules is unsupported, as the decrease of radium activity

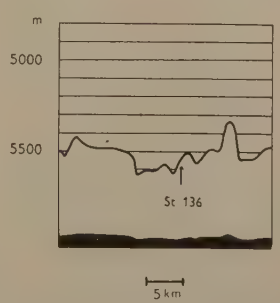

Fig. 11. Bottom topography in the vicinity of station 136.

from the surface towards the inner part occurs quite rapidly. In the first place we must reckon with a diffusion of radium, radially in the nodule, i. e. the radium distribution would be a dynamic equilibrium between the growth of radium from ionium and diffusion, adsorption and decay. The general curve trend with the two maxima may be explained in the same way as for Cores 69 B, 83 and 85 B. Fig. 4 shows the curve for the change of the rate of deposition. — For the Mn-nodule another reasoning is possible: it is well-known that in all manganese nodules there is not only an accumulation of mangenese but also of ferric hydroxide. It might, therefore, be quite possible that together with Fe $(OH)_3$ the ionium, too, is concentrated by factor 3—4, so that the higher radium concentration in the nodule is ionium supported in situ. Otherwise what is said about Core 69 B also applies to this core.

Core 87. Station, position, depth and topography as in Core 87 B. Core length 1043 cm.

General description: red clay with radiolaria and a content of $CaCO_3$ less than one per cent. Fe_2O_3 and MnO_2 for the uppermost metre appears from Fig. 13.

Distribution of radium concentration: in this case we have a fairly smooth trend of the curve for radium concentration, with a broad maximum of somewhat more than $30 \cdot 10^{-12}$ g Ra/g. The uranium equivalent is attained at 88 cm and is consistent throughout the whole core (10 m). According to RIEDEL one finds over the whole length of the core Tertiary radiolaria together with Recent radiolaria, which is consistent with the higher average rate of sedimentation of 2 mm/1000 years in this core. From the echogram (Fig. 11) it is readily understood that the distribution of radium concentration differs very much from that in Core 87 B. The factor $Ra_{sed.} : Ra_{Um}$ is 2.3.

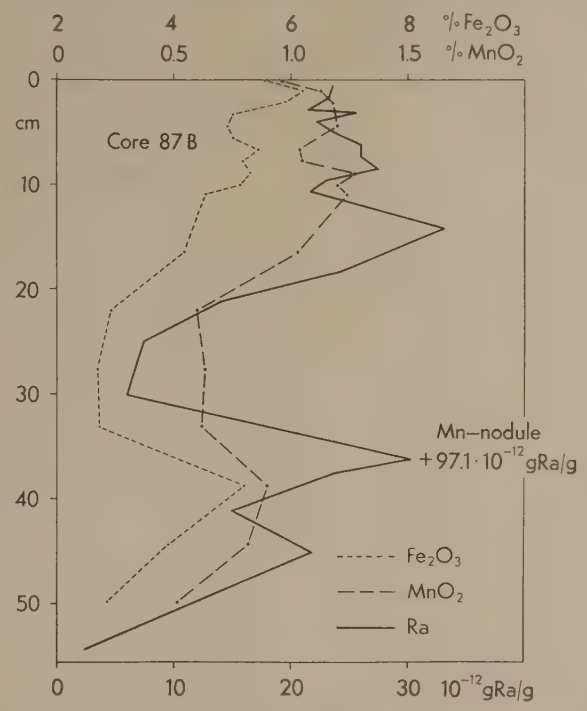

Fig. 12. The distribution of Ra, Fe_2O^3, and MnO_2 in Core 87 B.

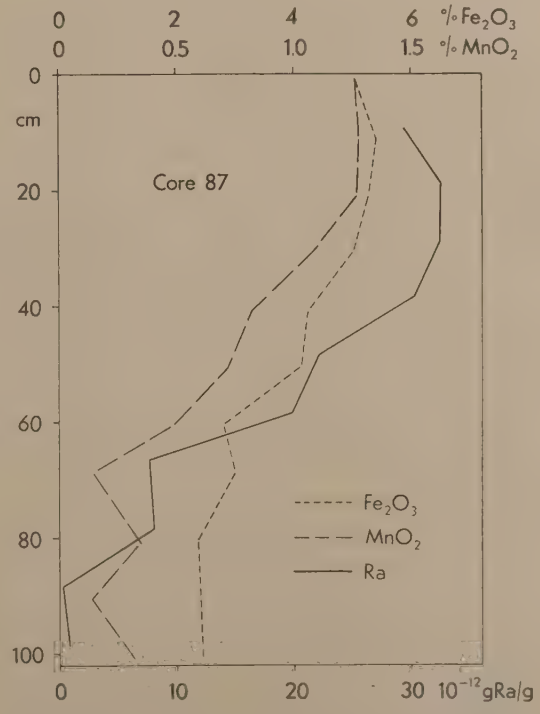

Fig. 13. The distribution of Ra, Fe_2O_3, and MnO_2 in Core 87.

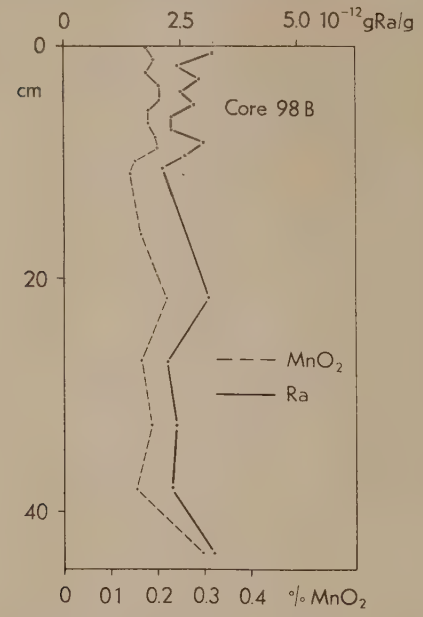

Fig. 14. The distribution of Ra and MnO_2 in Core 98 B.

Core 98 B. Station 148. Position 1° 40′ N 152° 37′ E. Depth 3670 m. Core length 45 cm.

General description: globigerina ooze reduced through loss of water during transport and storage from 45 to 41 cm. Between 8 and 9 cm a Mn-nodule, which was not measured. MnO_2 in Fig. 14.

Distribution of radium concentration: the radium concentration fluctuates between 1.7 and $3.5 \cdot 10^{-12}$ g Ra/g. On account of low radium content and small weights of the samples, the measurements are subject to some uncertainty. The uranium equilibrium is not known. The average rate of deposition found from the radium concentration is approximately 20 mm/1000 years. $MnO_2$and radium are well paralleled.

Core 101. Station 151. Position 2° 11′ N 145° 47′ E. Depth 4600 m. Core length 1077.5 cm.

General description of the examined part: somewhat calcareous clay. MnO_2 and $CaCO_3$ content are shown in Fig. 15.

Distribution of radium concentration: in this core are five maxima, the most pronounced having a radium concentration of $16 \cdot 10^{-12}$ g Ra/g. As appears from Fig. 15 some radium maxima are quite congruent with the MnO_2 curve and partly also parallel to $CaCO_3$. The reason for this is not clear; as mentioned

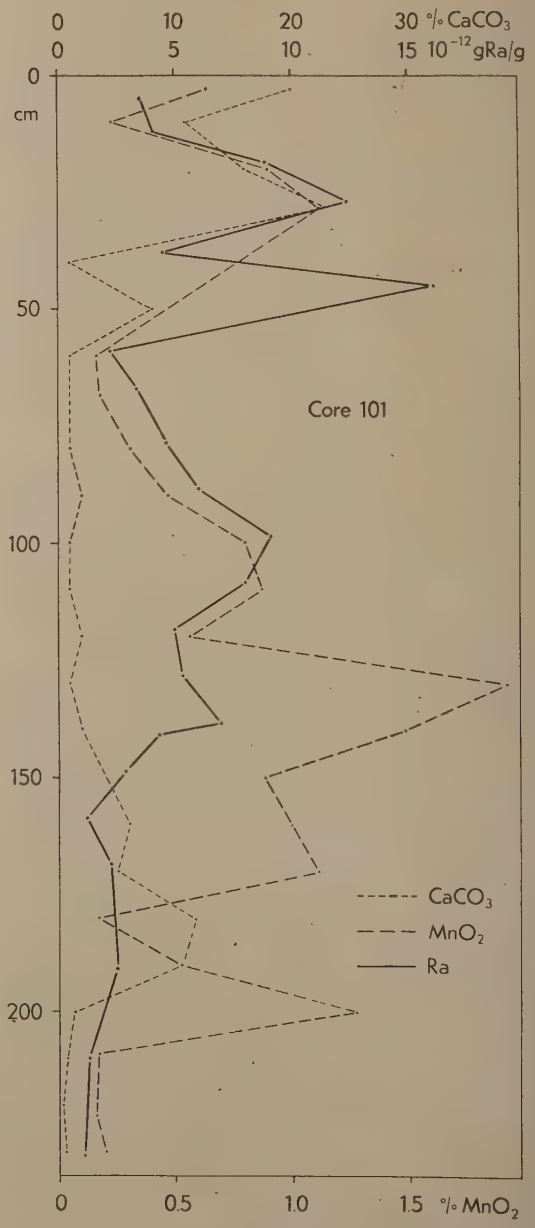

Fig. 15. The distribution of Ra, MnO_2, and $CaCO_3$ in Core 101.

above, the calcium carbonate content increases the rate of deposition and thus would reduce the radium concentration. Perhaps the explanation is found in the parallel trend of Mn and $CaCO_3$ observed in many cases. Moreover, the calcium carbonate content was relatively low, so that a possible diffusion and adsorption in the sediment, or the particular condition during the sedimentation process, may have been decisive for the radium distribution. — The average rate of deposition is 6—7 mm/1000 years. The curve for the fluctuation of the rate of deposition exhibits maxima for the sedimentation of that period as well as for the period ca. 80 000 and 250 000 years ago.

It is observed that the examined cores were taken in a region rich in volcanic activity which has most probably affected the sedimentation process. The vertical distribution of various species of radiolaria suggests a horizontal transport of sediment. This transport causes alterations in the rate of deposition. A comparison of these changes as a function of time in different core levels suggests for 5 cores (the distribution of the radium concentration in Core 85 B permits us to include this core) a high rate of deposition during a rather short period, about 100 000 years ago. If the alterations in the rate of sedimentation and ultimately the horizontal transport are attributed to volcanic eruptions (cf. Page 16), this means that about 100 000 years ago intense volcanic action took place. The fact that cores close to each other show different radium distribution may be due to the topography of the ocean floor. Such a distribution of the radium concentration with depth would also appear from alterations of the ionium supply caused by changes in the chemical conditions during the sedimentation process (perhaps also influenced by volcanic action); or the cause may be changes in the adsorption power of the sediment as well as diffusion and adsorption to some degree within the sediment.

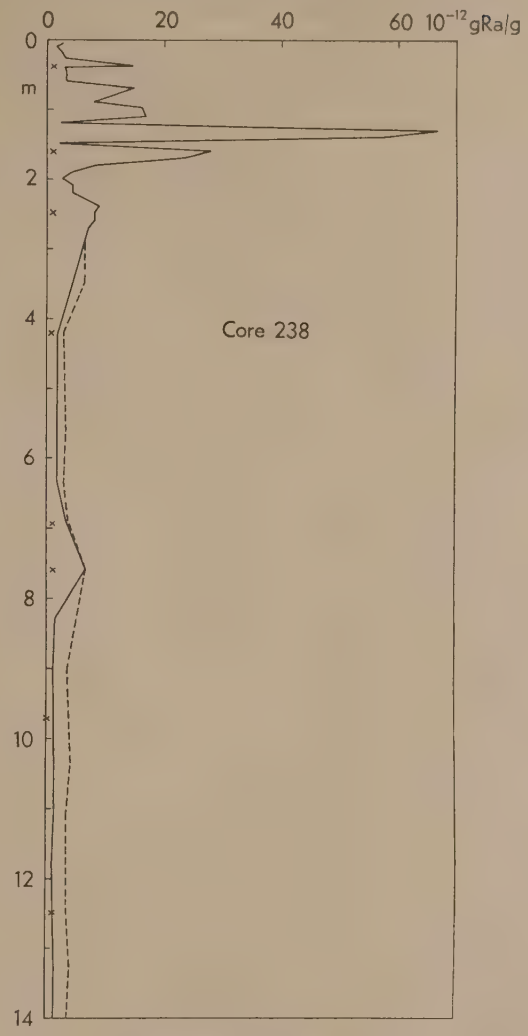

Fig. 16. The distribution of radium in Core 238. The dashed line gives the radium concentration corrected for the content of $CaCO_3$, on the assumption that $CaCO_3$-sediment does not content any radium. The crosses show the radium equilibrium values for the uranium values as measured by Hecht.

The ionium determinations by Isaac and Picciotto 1953 indicate a possible diffusion of radium but they are, so far, too few to admit of any conclusions about the rate of diffusion of the radium, about the essential factors in the process of ionium sedimentation and about the behaviour of ionium in the sediment.

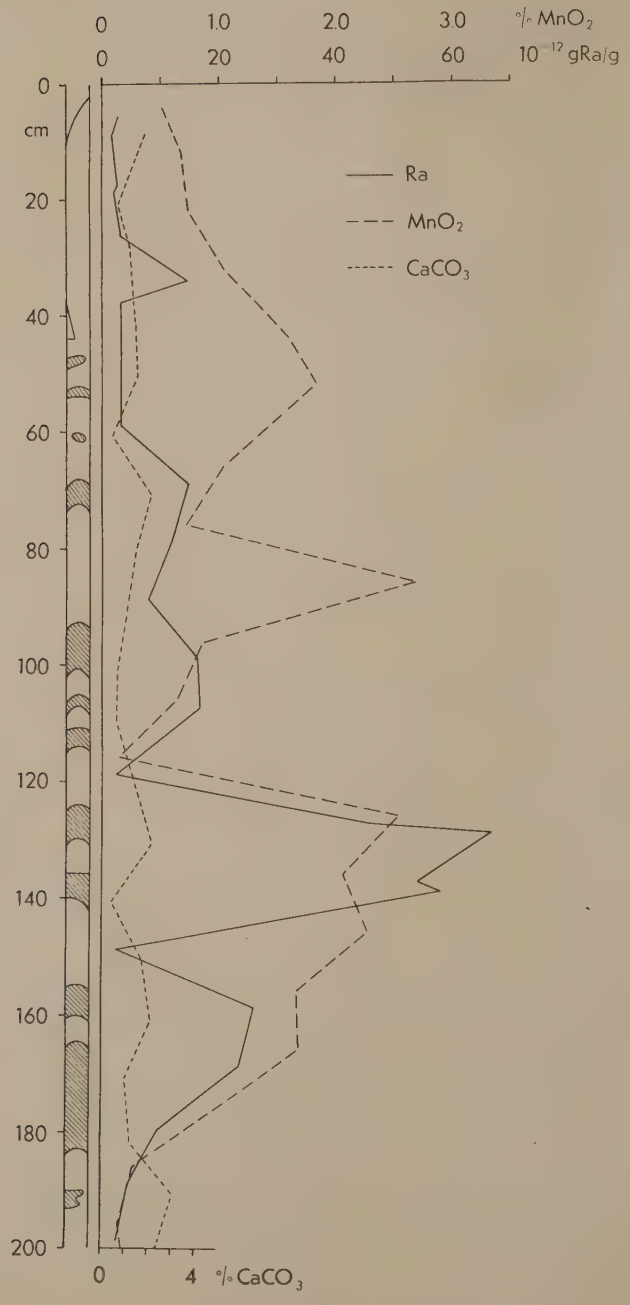

Fig. 17. The distribution of Ra, MnO_2, and $CaCO_3$ in the uppermost two meters of Core 238. The profil of the core is drawn, the dark layers in the sediment being marked by hatching.

The Cores from the Atlantic

Core 238. Station 339. Position 0° 07′ S 18° 12′ W. Depth 7315 m (Romanche-Deep). Core length 1412.4 cm.

General description: 0—349 cm dark clay with a red fraction, 349—665 cm gray clay and calcerous blue mud, 665—587 cm sand, 687—777 cm very blue mud, 777—1412.4 cm light, calciferous blue mud. The $CaCO_3$ distribution derived from spectrographic calcium determinations is considered in Fig. 16. Fig. 17 presents a diagram of the uppermost two metres of the core. The darker spots in the core are hatched. In addition, radium MnO_2 and $CaCO_3$ distribution are given.

Distribution of radium concentration: from Fig. 17 it is clear that all samples from the sediment levels, which are hatched, show a considerable higher radium concentration than the adjacent levels. In one level even $67 \cdot 10^{-12}$ g Ra/g were measured, which is the highest radium content in the sediment reported in this study. The cause of the dark colour of the sediment has not been established; possibly it is connected with Mn. The deepest radium maximum in this core is at 689—759 cm with almost $7 \cdot 10^{-12}$ g Ra/g. Duplaix and Cailleux have studied the level 681.5—682.5 cm; they found titanite. This suggests that the radium is uranium supported. As it is concentrated in some mineral grains, however, the uranium content can easily vary from one sample to the other. This would explain why Hecht in this level measured an uranium value which is below the radium equivalent. Furthermore, it is noticed in this core that the radium — uranium equilibrium is fairly high, about $2 \cdot 10^{-12}$ g Ra/g, which is raised still more by converting it to the corresponding value free from calcium carbonate. The average rate of deposition is about 20 mm/1000 years. The factor $Ra_{sed.} : Ra_{Um}$ is 4.7.

When interpreting the radium distribution we must firstly fall back on the variations

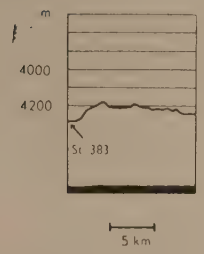

Fig. 18. Bottom topography in the vicinity of station 383.

of the ionium supply, which possibly apply to a different degree for adsorption of the depositing material, or the different chemical conditions for precipitations due, perhaps, to volcanic action. The other two alternatives for explaining the variation in the rate of sedimentation and diffusion of the radium in the sediment are of secondary importance. The diffusion and adsorption of radium as a cause demand, however, quite extreme presumptions, as the highest radium maxima are found far below the sediment surface.

Core 251. Station 355. Position 0° 37′ N 37° 06.5′ W. Depth 4540 m. Core length 948 cm.

General description: a great variety of sediment between blue mud, red clay, globigerina ooze and sand.

Distribution of radium concentration: the rate of deposition is so high that the measured radium concentration is mostly maintained by uranium supported radium. As long as accurate uranium determinations from the samples have not been made there is not much to say about this core.

Core 281 A. Station 383. Position 34° 54′ N 44° 20′ W. Depth 4281 m. Core length 61 cm. Topography: except some small irregularities rather flat (cf. Fig. 18).

General description: calciferous clay with foraminifera.

Distribution of radium concentration: the radium concentration lies between 1 and $3 \cdot 10^{-12}$ g Ra/g. The maximum is at 44 cm. The uranium equivalent is not attained.

Core 281. Station, position, depth and topography as in Core 281 A. Core length 340 cm.

General description: alternating red clay, blue mud and calcium ooze with tuff-layers. Calcium carbonate, MnO_2 and Fe_2O_3 content appears from Fig. 20.

Distribution of radium concentration: we find an almost ideal radium decay curve with a maximum of about $3 \cdot 10^{-12}$ g Ra/g at 20 cm; five narrow radium maxima are superimposed on this curve. All of them except the second maximum coincide with the dark layers in the sediment, probably tuff-layers in red clay. To what degree these maxima are uranium supported has not been settled.

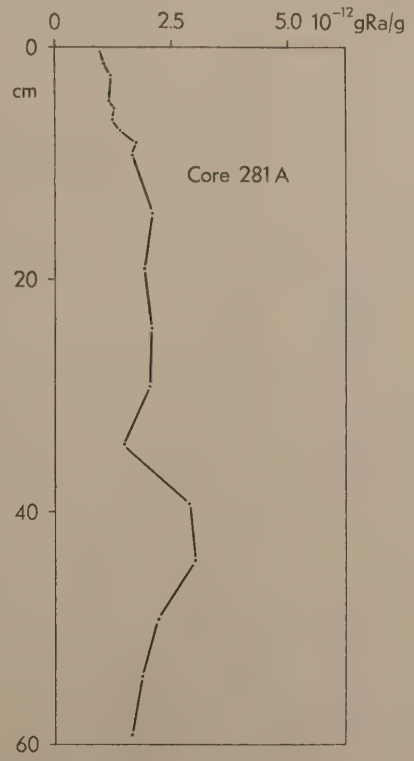

Fig. 19. The distribution of radium in Core 281 A.

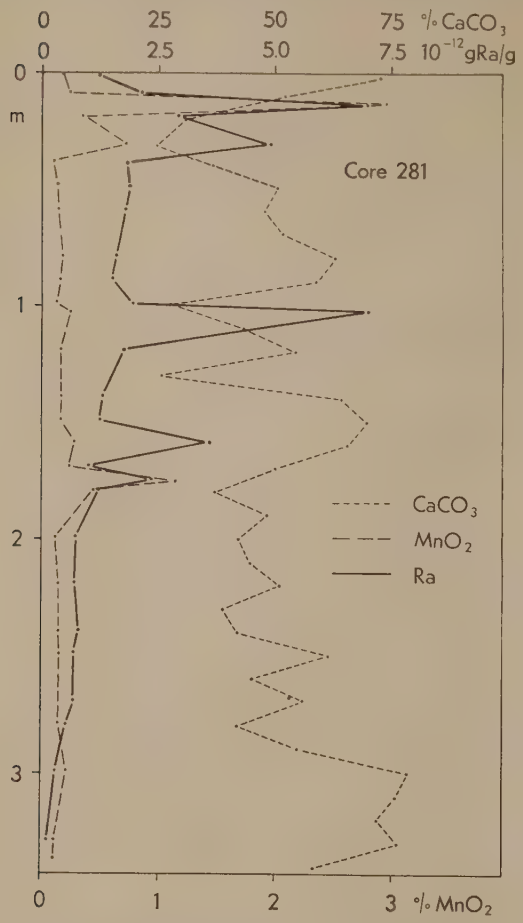

Fig. 20. The distribution of Ra, MnO_2, and $CaCO_3$ in Core 281.

Anyhow, three of them run parallel with Mn. The average rate of sedimentation amounts to 7—10 mm/1000 years. Comparing with 281 A it may be concluded that 10—20 cm of the upper part are missing.

If the maxima are not uranium supported the interpretation is likely to be a ionium supply.

It may be concluded that also the radium distribution in the cores of the Atlantic, in particular in Core 238, are probably influenced by submarine volcanic action. The rate of deposition generally being higher in the Atlantic, not so much horizontal transportation, viz. alterations in the rate of sedimentation, but all the more variations in the ionium supply, may be decisive for the pronounced extremes in the radium distribution curves.

Summary

From the present radium, ionium and uranium measurements it may be concluded that the radium occurring in the upper layers of sediment is ionium supported. Further, it was found that, generally, the vertical distribution of the radium concentration found in sediments differs essentially from the theoretical distribution, which is obtained with constant ionium supply per time unit, constant rate of sedimentation and immobility of the radioactive elements in situ. This behaviour of the radium necessitates methodic investigations on as large a scale as possible. The present work does not claim to be conclusive. By comparing the measured distribution of radium with the distribution of Mn, $CaCO_3$, radiolaria etc., it is gathered that mainly three processes are of essential influence on the vertical distribution of radium in the sediment:

1). Alteration of the ionium supply per time unit
   a) by variation in the adsorption power of the depositing sediment for ionium, or
   b) variations of the chemical conditions in the sea-water, causing the sedimentation of ionium and probably due to volcanic action.
2). Variation of the rate of sedimentation by horizontal transport which may also be induced by volcanic action.
3). Diffusion and adsorption of radium in the sediment.

Different methods for determining the rate of sedimentation have been described. How these should be applied depends on the locality and may be established only by a thorough

investigation of the cores. This has not yet been accomplished. However, values of the rate of sedimentation were found on the understanding that the amount of ionium supported radium in the sediment was possible to be determined, and that the radium concentration in L_0, the layer where the Ra-U equilibrium is attained, was neither changed by diffusion nor deviates much from the average ionium supply per time unit, or from the average rate of sedimentation per time unit. The values found are shown in Table 5.

The ratio $Ra_{sed.} : Ra_{Um}$ (Table 3) being in almost all Pacific and Atlantic cores > 1, it would appear, that the uranium concentration in sea-water, or the ionium supply to the sea, has not been constant in time, but, it was probably considerably higher after the glacial periods: While this paper was in the press, reports from uranium measurements published by Nakanishi (1951), Smith-Grimaldis (1953) and by Stewart and Bentely (1953) were obtained. They give values of from 1 to $3 \cdot 10^{-6}$ g U/l, with a preference for the higher values. Assuming this to be the average content in ocean water and not due to occasional variation in the distribution of uranium, only the ratio $Ra_{Sed.} : Ra_{Um}$ is affected and becomes nearly 1. My essential conclusions remain unchanged. Another result suggests that about 100 000 years ago an intense volcanic activity occurred in the Pacific.

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TABLE 1 a and b. Test, showing that the radium is totally extracted from sediment samples by treatment with HCl.

Core-number	Depth from top (cm)	Treatment of the sediment	Radium content in 10^{-12} g/g
59	150—151.5	carbonate fusion, acid solution	8.5
		carbonate fusion, alkal. solution	0.0
59	150—151.5	extraction with HCl .	7.9
		carb.fus. of the residuum insoluble in HCl, acid sol.	0.0
		carb.fus. of the residuum insoluble in HCl, alkal. sol.	0.0
59	160—161.5	carbonate fusion, acid solution	10.9
		carbonate fusion, alkal. solution	0.0
59	160—161.5	extraction with HCl .	11.1
		carb.fus. of the residuum insoluble in HCl, acid sol.	0.0
		carb.fus. of the residuum insoluble in HCl, alkal. sol.	0.0

Core-number	Depth from top (cm)	radium cont. soluble in HCl 10^{-12} g/g	radium cont. measured in the residuum insoluble in HCl after carb.fus. in 10^{-12} g/g	
			acid solution	alkaline solution
76	40 — 41.5	1.5	0.0	
76	200 —201.5	0.1	0.1	
83 B	15 — 16.1	30.1	0.0	
83	3.5— 4.5	27.9	0.1	
83	12.5— 14.5	0.4	0.2	
83	16 — 17	0.5	0.0	
85 B	38.2— 39.4	3.8	0.0	
85	3 — 4	0.9	0.1	
86 B	6.6— 7.7	49.8	2.9	
86 B	30.8— 31.9	30.2	1.2	
86	22.5— 23.5	2.2	0.1	
87 B	24.5— 25.6	7.4	0.0	
87 B	29.4— 30.5	4.6	x 1.5	
87 B	35.6— 36.7	30.2	0.1	
87 B	36.7— 38.3	23.6	0.1	
87 B	40.6— 41.7	12.4	x 2.5	
87	9 — 10	29.2	0.0	
87	38 — 39	30.2	0.1	
87	66 — 67	7.7	0.2	
238	128 —129.5	66.7	0.6	0.2
238	148 —149.5	2.3	0.1	0.0
238	158 —159.5	28.0	0.0	0.0
238	758 —759.5	6.9	0.3	0.0

x These amounts were measured on residua, from which radium was not thoroughly washed out.

TABLE 2. The distribution of the radium concentration in deep-sea sediment cores.

Core 69 B. Station 102. Position 13° 25′ S 149° 30′ W. Depth 4625 m. Length of the core 44 cm. General description: red clay with very numerous crystals of philipsite.

Depth from top of the core (cm)	10^{-12} g Ra/g	
0.0 — 0.1	x 37.6	
0.1 — 0.3	x 41.7	
0.3 — 0.5	x 48.0	
0.5 — 0.75	x 50.0	
0.75— 1.0	x 51.7	
1.0 — 1.5	x 50.0	x 52.0
1.5 — 2.0	x 51.2	
2.0 — 2.5	x 11.4	
2.5 — 3.0	x 21.2	
3.0 — 3.5	x 35.7	
3.5 — 4.0	x 17.7	
4.0 — 5.0	x 51.7	
5.0 — 6.0	x 41.6	
6.0 — 7.0	x 12.5	
7.0 — 8.0	x 40.0	x 38.0
10.0 —12.0	x 17.7	
12.0 —14.0	x 13.5	
14.0 —16.0	x 3.6	
18.0 —20.0	x 1.3	
24.0 —25.0	1.4	
32.0 —33.0	43.8	44.3
42.5 —44.0	5.0	5.0

x = measured by H. PETTERSSON.

Core 76 B. Station 114. Position 3° 45′ N 149° 44′ W. Depth 5155 m. Length of the core 29.5 cm. General description: above 11 cm red clay poor in calcium carbonate with numerous radiolaria, below fine calcareous ooze.

Depth from top of the core (cm)	10^{-12} g Ra/g	
0.0 — 0.1	10.5	
0.1 — 0.3	11.6	
0.5 — 0.75	9.8	
0.75— 1.0	12.0	
1.0 — 1.5	12.5	
1.5 — 2.0	16.6	
2.0 — 2.5	8.5	
2.5 — 3.0	9.9	
3.0 — 3.5	14.5	
3.5 — 4.0	14.7	
4.0 — 5.0	9.5	
5.5 — 6.5	1.0	
8.0 — 9.0	7.9	
9.0 —10.0	0.9	1.1
14.0 —15.0	0.9	
15.5 —16.5	0.4	
19.0 —20.0	0.3	
20.5 —22.0	0.2	
24.0 —25.0	0.4	
25.5 —27.0	0.3	

Core 76. Station 114. Position 3° 45′ N 149° 44′ W. Depth 5155 m. Length of the core 1354.5 cm. General description: clay and calcareous sediment.

Depth from top of the core (cm)	10^{-12} g Ra/g
1.5— 3.0	14.4
13.0— 14.0	9.6
25.0— 26.0	3.0
40.0— 41.5	1.5
53.0— 54.0	1.3
65.0— 66.0	0.1
87.5— 88.5	0.1
101.5— 102.5	0.5
144.0— 145.0	0.2
200.0— 201.5	0.1
300.0— 301.5	0.1
400.0— 401.5	0.0
600.0— 601.5	0.1
710.0— 711.5	0.2
801.5— 803.0	0.2
910.0— 911.5	0.3
931.5— 933.0	0.3
1030.0—1031.5	0.4
1130.0—1131.5	0.0
1230.0—1231.5	0.0
1351.5—1354.0	0.1

Core 83 B. Station 130. Position 08° 40′ N 169° 28′ W. Depth 5440 m. Length of the core 30 cm. General description: red clay.

Depth from top of the core (cm)		10^{-12} g Ra/g			Average
0.6— 0.8		20.8	17.5	22.3	20.3
1.7— 1.9		25.4	24.4	24.5	24.8
2.8— 3.0		28.4	27.2		27.8
3.9— 4.1		29.1	30.0		29.6
5.0— 5.3		28.5	29.4		28.9
6.1— 6.4		33.3	32.8		33.1
7.2— 7.5		34.2	33.2		33.7
8.3— 8.6		39.1	37.4		38.3
9.4— 9.7		39.4	35.7		37.6
10.5—10.8		38.7	40.0		39.4
11.1—12.2	I	25.7			34.4
	II	8.9			
12.2—13.9	I	16.1			34.8
	II	18.7			
13.9—15.0	I	19.5			35.8
	II	16.3			
15.0—16.1	I	22.1			30.1
	II	8.0			
20.5—21.6		18.1			27.4
	II	9.3			
	III	0.0			
26.1—27.2	I	19.1			25.0
	II	5.9			

The measured solution I did not contain all radium in the sample as the washing with HCl was not complete. Solution II was obtained by a new thorough washing of the residuum insoluble in HCl. The solution III was produced by a third washing.

Core 83. Station 130. Position 8° 40′ N. 169° 28′ W. Depth 5440 m. Length of the core 295 cm. General description: red clay poor in calcium carbonate.

Depth from top of the core (cm)	10^{-12} g Ra/g
3.5— 4.5	27.9
8.0— 9.0	1.4
11.5—12.5	0.0
12.5—14.5	0.4
16.0—17.0	0.5
21.5—22.5	9.7
26.0—27.0	44.1
27.0—29.0	45.1
31.5—32.5	46.4
36.0—37.0	26.8
41.5—42.5	5.5
46.0—47.0	0.0
51.5—52.5	0.8
56.0—57.0	1.2
64.0—65.0	0.1

Core 85 B. Station 132. Position 5° 34′ N 172° 12′ W. Depth 5590 m. Length of the core 57 cm. General description: red clay.

Depth from top of the core (cm)	10^{-12} g Ra/g	
0.6— 1.1	27.7	28.3
1.7— 2.3	27.8	29.3
2.8— 3.1	28.6	
4.0— 4.3	34.4	
5.1— 5.4	35.6	
6.3— 6.6	30.8	
7.4— 7.7	33.4	
8.5— 8.8	24.7	
9.7—10.0	25.7	
10.8—11.1	20.5	
15.4—16.5	22.8	
16.5—17.1	25.1	
21.1—22.2	14.9	
26.8—27.9	10.6	
32.5—33.6	7.3	
38.2—39.4	3.8	
43.9—45.0	3.4	
49.5—50.7	23.2	
55.3—56.4	21.7	

Core 85. Station 132. Position 5° 34′ N 172° 12′ W. Depth 5590 m. Length of the core 1083 cm. General description: red clay poor in calcium carbonate.

Depth from top of the core (cm)	10^{-12} g Ra/g	
3.0— 4.0	0.9	
8.0— 9.0	0.6	0.7
18.0—19.0	0.3	
28.0—29.0	0.1	
51.5—52.5	0.0	
61.5—62.5	0.0	
71.5—72.5	0.2	
81.5—82.5	0.0	
93.0—94.0	0.0	

Core 86. Station 134. Position 4° 02′ N 172° 19′ W. Depth 5500 m. Length of the core 1038,5 cm. General description: red clay poor in calcium carbonate with numerous radiolaria.

Depth from top of the core (cm)	10^{-12} g Ra/g
3.5— 5.0	6.0
12.5—14.0	4.3
22.5—23.5	2.2
31.5—32.5	2.4
41.5—42.5	1.6
52.0—53.0	1.2
61.5—62.5	1.3
70.0—71.0	0.8
81.5—82.5	0.6
93.0—94.5	0.7

Core 86 B. Station 134. Position 4° 02′ N 172° 19′ W. Depth 5500 m. Length of the core 54 cm. General description: red clay with radiolaria, poor in calcium carbonate.

Depth from top of the core (cm)	10^{-12} g Ra/g		
0.0— 0.1	20.1		
0.1— 0.3	29.9	28.2	
0.3— 0.5	29.8		
0.5— 0.8	31.0		
0.8— 1.1	30.0		
1.1— 1.7	33.6		
1.7— 2.2	34.0		
2.2— 2.8	41.3		
6.0— 6.6	49.8		
6.6— 7.7	41.0		x 43.9
7.7— 8.8	53.0		
8.8— 9.9	45.3		
11.5—12.7	43.4		
12.7—14.3	34.0		
14.3—15.4	45.1		
17.0—18.2	41.5		
18.2—19.3	52.2		
19.3—20.9	44.8		
25.3—26.4	30.7		
30.8—31.9	30.2		x 31.4
33.5—34.6	24.2		
38.5—39.6	24.2		
44.5—45.6	27.2		
52.9—54.0	19.1		

x = corrected for the radium content of the residuum insoluble in HCl, which was measured after a fusion with carbonate.

Core 87 B. Station 136. Position 2° 23′ N 173° 50′ W. Depth 5560 m. Length of the core 55 cm. General description: red clay poor in calcium carbonate.

Depth from top of the core (cm)		10^{-12} g Ra/g		Average
0.6— 0.8		23.6		
1.7— 1.9		23.2		
2.8— 3.0		21.5		
3.0— 3.3		25.5		
3.9— 4.1		22.2		
5.0— 5.3		23.8		
6.1— 6.4		26.0		
7.2— 7.5		26.0		
8.3— 8.6		27.5		
9.4— 9.7		23.1		
10.5—10.8		21.7	26.0	23.8
13.3—13.9	I	27.4		33.0
	II	5.6		
17.8—18.9	I	17.6		24.0
	II	6.4		
20.6—21.7	I	11.1		14.2
	II	3.1		
24.5—25.6	I	5,5		7.4
	II	1.9		
29.4—30.5		4.6		x 6.1
35.6—36.7	I	23.1		30.2
	II	7.1		
35.6—36.7		97.1	97.5	97.3
36.7—38.3	I	17.7		23.6
	II	5.9		
40.6—41.7		12.4		x 14.9
44.5—45.6	I	15.2		21.8
	II	6.6		
53.4—55.0	I	0.9		2.5
	II	1.6		

The measured solution I did not contain all radium in the sample as the washing with HCl was not complete. Solution II was obtained by a new thorough washing of the residuum insoluble in HCl.

x = corrected for the radium content of the residuum insoluble in HCl, which was measured after a fusion with carbonate.

Core 87. Station 136. Position 2° 23′ N 173° 50′ W. Depth 5560 m. Length of the core 1020 cm. General description: red clay with numerous radiolaria.

Depth from top of the core (cm)	10^{-12} g Ra/g
9.0— 10.0	29.2
18.0— 19.0	32.4
28.0— 29.0	32.4
38.0— 39.0	30.2
48.0— 49.0	22.0
58.0— 59.0	19.8
66.0— 67.0	7.7
78.0— 79.0	8.1
88.0— 89.0	0.3
98.0— 99.0	0.9
138.0—139.0	0.2
178.0—179.0	0.0
198.0—199.0	0.0
227.5—229.0	0.0
257.5—259.0	0.1
315.5—317.0	0.5
407.5—409.0	0.2
497.5—499.0	0.1
597.5—599.0	0.1
797.5—799.0	0.1
897.5—899.0	0.4
997.5—999.0	0.0

Core 98 B. Station 148. Position 1° 40′ N 152° 37′ E. Depth 3670 m. Length of the core 45 cm. General description: globigerina ooze.

Depth from top of the core (cm)	10^{-12} g Ra/g		Average
0.5— 0.8	3.2		3.2
1.6— 1.9	2.2	2.6	2.4
2.7— 3.0	2.9		2.9
3.8— 4.1	2.5		2.5
4.9— 5.2	2.9	2.8	2.8
6.0— 6.3	1.8	2.5	2.3
7.1— 7.4	1.7	2.9	2.3
8.2— 8.5	3.0	3.0	3.0
9.3— 9.6	1.9	3.2	2.6
10.4—10.7	2.1		2.1
21.4—21.9	2.8	3.4	3.1
26.9—27.5	1.8	2.6	2.2
32.4—32.9	2.4		2.4
37.8—38.4	2.3		2.3
43.3—43.9	3.2		3.2

Core 101. Station 151. Position 2° 11′ N 145° 47′ E. Depth 4600 m. Length of the core: 1072 cm. General description: clay somewhat calcareous.

Depth from top of the core (cm)	10^{-12} g Ra/g
4.5— 5.5	3.6
11.5— 12.5	4.1
18.0— 19.0	8.9
26.5— 27.5	12.4
37.5— 38.5	4.4
44.5— 45.5	16.1
58.0— 59.0	2.3
66.5— 67.5	3.4
78.0— 79.0	4.6
88.0— 89.0	6.0
98.0— 99.0	9.1
108.0—109.0	8.0
118.0—119.0	5.0
128.0—129.0	5.3
138.0—139.0	6.9
140.0—141.5	4.3
148.0—149.0	2.9
158.0—159.0	1.2
168.0—169.0	2.2
190.0—191.5	2.5
209.0—210.5	1.3
230.0—231.5	1.1

The cores from the Atlantic.

Core 238. Station 339. Position 0° 07′ S 18° 12′ W. Depth 7315. (Romanche Deep). Core length 1412.4 cm.

Depth from top of the core (cm)	10^{-12} g Ra/g	
5 — 6	2.6	2.8
8 — 9.5	1.7	
17 — 18	2.5	
18 — 19.5	2.1	
25 — 26	3.2	
26 — 27.5	3.1	
33.5— 34.5	14.6	
38 — 39.5	3.2	
48 — 49.5	3.2	3.4
58 — 59.5	3.3	
68 — 69.5	14.9	
78 — 79.5	11.8	
88 — 89.5	7.9	
98 — 99.5	16.4	
107 — 108.5	16.9	
118 — 119.5	2.3	
126.5— 128.1	45.7	
128 — 129.5	66.7	
128 — 129.5	46.5	
136.5— 138.0	54.0	
138 — 139.5	58.0	
148 — 149.5	2.2	2.4
158 — 159.5	28.0	
168 — 169.5	23.4	
179 — 180.5	9.7	
188 — 189.5	4.6	
198 — 199.5	2.7	
208 — 209.5	4.5	
218 — 219.5	4.4	
228 — 229.5	6.8	
238 — 239.5	9.0	
248 — 249.5	8.3	
258 — 259.5	8.3	
268 — 269.5	7.2	
278 — 279.5	7.0	
290 — 291.5	6.5	
349.5— 351	4.4	
418.5— 420	2.0	
488 — 489.5	2.1	
558 — 559.5	2.0	
628 — 629.5	1.9	
688 — 689.5	3.4	
758 — 759.5	6.9	
828 — 829.5	1.7	
898 — 899.5	1.3	
1038 —1039.5	1.5	
1108 —1109.5	1.5	
1178 —1179.5	1.3	
1248 —1249.5	1.3	1.6
1328 —1329.5	1.6	
1398 —1399.5	1.5	

Core 251. Station 355. Position 0° 37′ N 37° 06.5′ W. Depth 4540 m. Length of the core 948 cm.

Depth from top of the core (cm)	10^{-12} g Ra/g	
3.0— 5.0	2.26	
12.0— 14.0	2.29	2.27
23.5— 25.5	1.26	
40.5— 42.5	1.09	
87.0— 89.5	2.11	
122.0—124.0	2.10	
171.5—173.5	2.62	
227.5—229.5	2.38	
332.0—334.0	1.03	
393.0—395.0	1.10	
447.5—449.5	0.88	
501.5—503.5	2.05	
557.5—559.5	1.18	
617.5—619.5	0.93	
692.0—694.0	1.91	
786.0—788.5	2.14	

Core 281 A. Station 383. Position 34° 54′ N 44° 20′ W. Depth 4281 m. Length of the core 61 cm. General description: calciferous clay with foraminifera.

Depth from top of the core (cm)	10^{-12} g Ra/g
0.0— 1.0	0.99
1.0— 2.0	1.05
2.0— 3.0	1.18
4.5— 5.0	1.15
5.0— 5.5	1.26
6.0— 6.5	1.22
7.0— 7.5	1.39
8.0— 8.5	1.74
9.0— 9.5	1.66
14.0—14.5	2.09
19.0—19.5	1.91
24.0—24.5	2.06
29.0—29.5	2.02
34.0—34.5	1.46
39.0—39.5	2.88
44.0—44.5	3.00
49.0—49.5	2.20
54.0—54.5	1.86
59.0—59.5	1.63

Core 281. Station 383. Position 34° 54′ N 44° 20′ W. Depth 4281 m. Length of the core 340 cm. General description: alternating red clay, blue mud and calcareous ooze with tuff-layers.

Depth from top of the core (cm)	10^{-12} g Ra/g	
0.5— 2.0	1.2	
8.0— 9.5	2.1	
13.0— 14.5	6.6	7.3
18.0— 19.5	2.9	3.0
30.0— 31.5	4.7	5.2
38.0— 39.5	1.8	
48.0— 49.5	1.8	2.1
58.0— 59.5	1.8	
78.0— 79.5	1.6	1.7
88.0— 89.5	1.4	1.7
98.0— 99.5	1.9	
101.5—103.0	7.0	7.0
118.0—119.5	1.8	
138.0—139.5	1.3	
148.0—149.5	1.2	
158.0—159.5	3.6	3.7
168.0—169.5	1.0	
174.0—175.5	2.4	
178.0—179.5	1.2	
198.0—199.5	0.7	
218.0—219.5	0.7	0.7
238.0—239.5	0.8	
248.0—249.5	0.7	
267.0—268.5	0.7	
278.0—279.5	0.5	
298.0—299.5	0.3	
328.0—329.5	0.1	

TABLE 3. Ra_{sed}/Ra_{Um}.

1	2	3	4	5	6	7
69 B	53 a)	50	0.5	5.9	4625	3.1
76 B	70	16	0.4	0.3	5155	0.1 c)
83	76	47	0.5	2.3 b)	5440	1.3
87 B	77 a)	55	0.5	2.7	5560	1.8
87	78	88	0.5	4.2	5560	2.3
101	62	210	1.2	4.2	4600	2.2
238	75	420	2.2	9.1	7315	4.7
281	60	280	0.5	1.9	4280	1.0

Column 1 = core number.

Column 2 = average percentage of water content in g/g in the (considered) core length.

Column 3 = length of the core in cm over which the radium content was integrated.

Column 4 = radium content/g sediment, assumed as uranium-supported.

Column 5 = Ra_{sed} = radium content in 10^{-10} g in a column of sediment of one cm square. The radium content, equivalent to uranium is subtracted. Density of the dried sediment = 2,6

Column 6 = station depth in m.

Column 7 = $Ra_{sed}/Ra_{Um} \cdot Ra_{Um} = 1.9 \cdot 10^{-10}$ is the equilibrium radium value, equivalent to the uranium content in a column of seawater of one cm square and of a depth = the mean ocean depth of 4 117 m, assuming a mean concentration of $1.3 \cdot 10^{-6}$ g U/l.

a) The average water content in Core 69 and 87 resp. in the corresponding length of the core, was also used for the B-cores.

b) The true value should be higher as a part of the first maximum in radium is lost (see below)

c) Uncertain value. The lower part of the core contains fine calcareous ooze. The low radium content and the high rate of deposition cause a high error in the integral Ra_{sed}.

TABLE 4. The uranium content of bottom cores

Core-number	cm from top	Uranium content measured	Radium value equivalent to the measured uranium cont.	Radium content measured
76	1.5— 3.0	0.76	0.27	14.4
76	40 — 41.5	11.4	4.0	1.5
76	200 — 201.5	7.16	2.5	0.6
76	300 — 301.5	2.72	0.95	0.1
76	400 — 401.5	1.8	0.63	0.0
76	500 — 501.5	1.46	0.51	
76	600 — 601.5	1.1	0.38	0.1
76	710 — 711.5	1.18	0.41	0.2
76	801.5— 803	0.96	0.33	0.2
76	910 — 911.5	2.64	0.92	0.3
76	931.5— 933	2.40	0.84	0.3
76	1030 —1031.5	1.42	0.5	0.4
76	1130 —1131.5	2.10	0.73	0.0
76	1230 —1231.5	2.25	0.78	0.0
76	1351.5—1354	2.26	0.79	0.1
69 B	4.1— 5.2	4.4	1.5	51.7
83	4.5— 6.5 x	0.7	0.25	27.9
83	12.5— 14.5 x	1.2	0.42	0.4
86 B	6.6— 7.7	3.64	1.27	41.0
86 B	14.3— 15.4	3.33	1.16	45.1
86 B	18.2— 19.3	2.40	0.84	52.2
86 B	30.8— 31.9	2.66	0.93	30.2
86 B	44.5— 45.6	2.4	0.84	27.2
87 B	3.0— 3.3	4.0	1.4	21.5
87 B	40.6— 41.7	31.05	10.8	12.4
238	48 — 49.5	3.50	1.22	3.2
238	128 — 129.5	1.91	0.66	67.6
238	158 — 159.5	2.21	0.78	28.0
238	248 — 249.5	1.91	0.66	8.3
238	418.5— 420	1.40	0.49	2.0
238	688 — 689.5	1.75	0.61	3.4
238	758 — 759.5	2.43	0.85	6.9
238	968 — 969.5	1.14	0.40	
238	1248 —1249.5	2.94	1.03	1.32
251	447.5— 449.5 xx	2.1	0.73	0.88
251	501.5— 503.5 xx	2.35	0.82	2.05

x Samples measured by V. Kröll.

xx Samples measured by F. Hecht and V. Kröll.

TABLE 5. The mean rate of sedimentation during the last 3—400000 years.

Corenumber	mean rate of sedimentation in mm per 1000 years
69 B	1.3
76 B	3—4 (part with red clay) resp. 15—20 (calcareous part of the sed.)
76	—
83 B	1—2
83	1.2—1.5
85 B	1.7
85	—
86 B	1.2
86	—
87 B	1.2—1.3
87	2
98 B	20
101	6—7
238	20
251	—
281 A	—
281	7—10

The probable error is about 20 %.

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